Origin of Batesford Limestone (Miocene), Victoria

By R. J. Foster

Superintendent Petroleum Engineer, The Broken Hill Proprietary Co. Ltd., 440 Collins Street, Melbourne 3000

Abstract

The echinoid fauna of the Batesford Limestone (Miocene, Australia) is examined. Comparison with living faunas of similar aspect indicates that only the burrowing sea urchins of the order Spatangoida were indigenous to the carbonate sediment, and that they lived at a water depth of 20-200 m. The regular urchins, on the other hand, lived in very shallow water on a rocky bottom. It is suggested that they were part of a rock dwelling community developed on an adjacent granite massif called the Dog Rocks. Fragments derived from this community accumulated in quiet water off the lee flank of the topographical high to form the skeletal carbonate sand body known as the Batesford Limestone.

Thus the character of the Batesford Limestone is attributed to the pre-existence of a suitable sediment source—a flourishing community of encrusting and sedentary organisms on the Dog Rocks.

If subsequently buried by impermeable sediments, a limestone unit similar in lithology and geometry to the Batesford Limestone could constitute a stratigraphic trap for hydrocarbons. Such a limestone should be sought in association with a palaeo-high which could have provided the shallow water and hard bottom where calcareous organisms would flourish.

Introduction

The purpose of this article is to investigate the palaeoecology of the fauna contained in a lithological unit so that the depositional environment and mode of origin of the body may be deduced.

The rock unit studied is the Batesford Limestone, and the ecology of its echinoid fauna is inferred from a comparison with living assemblages from carbonate environments.

Geological Setting

Dog Rocks

The Dog Rocks overlook the valley of the Moorabool R. near Batesford about eight km NW. of Geelong, Victoria (Fig. 1). They comprise a granite outcrop about 2½ by 1 km with its long axis trending WNW. to ESE. and its crest about 70m above the top of the adjacent Batesford Limestone.

Batesford Limestone

A brief general description of the Batesford Limestone, and list of fauna, was published by Hall & Pritchard (1892). More detailed subsequent descriptions are those of Chapman (1910), with emphasis on the fauna, particularly the foraminifera, and Bowler (1963) with emphasis on lithology, particularly grain size distribution and mineralogy. The deposit has been included in faunal units 8 and 9 of Carter (1958, p. 24) corresponding to a Lower Miocene age (Ludbrook 1967, fig. 3).

SIMPLIFIED GEOLOGY OF THE GEELONG DISTRICT

Fig. 1

Hall and Pritchard recognized two distinct lithologies within the Batesford Limestone:

(i) foraminiferal limestone composed of dominant larger foraminifera such as *Lepidocyclina* with subordinate bryozoa, echinoid spines and calcareous algae, and

(ii) bryozoal limestone composed largely of bryozoa but with some echinoid spines and plates, foraminifera and a few lamellibranch shells.

Both are skeletal lime grainstones in the terminology of Dunham (1962) and, due to absence of pore-filling cement, are generally friable and highly permeable.

Measurements performed by Core Laboratories Incorporated on two samples of bryozoal limestone, one clean and one containing abundant granite sand, yielded the following results:

	Porosity per cent	Permeability millidarcies
Clean sample	53	2700
Sandy sample	36	5200

The lack of correlation between porosity and permeability is attributable to the presence of a greater proportion of void-containing fossils, and hence unconnected pores, in the clean limestone.

The Batesford Limestone has a maximum thickness of at least 70 m (Bowler 1963, p. 90), of which approximately the uppermost 10 m could be described as bryozoal limestone, and the next 15 m as foraminiferal limestone (Spencer-Jones 1967, p. 161). The balance of the deposit is again bryozoal limestone, though without any addition of scattered *Lepidocyclina* as in the upper part. The Limestone grades vertically and laterally into marly sediments of the Fyansford Clay and butts against the flank of the Dog Rocks, as indicated by the inclusion of abundant granite fragments in its basal portion (Chapman 1910, p. 267).

Drilling by Australian Portland Cement Co. Ltd. has established that the Limestone is confined to the eastern and south-eastern sides of the Dog Rocks granite massif (Spencer-Jones 1967, p. 159). The beds dip gently away from the granite, towards the south-east, at 1-2° (Bowler 1963, p. 91) and this may represent depositional dip.

Echinoid Fauna of Batesford Limestone

Both regular and irregular echinoids are well represented in the Batesford Limestone.

Subclass Regularia

Relatively stout-tested regular echinoids of the genera *Phyllacanthus, Strongylocentrotus, Heliocidaris* and *Zenocentrotus* occur in the Limestone (Philip 1963, 1965).

Clark (1946, p. 281) states that the stout primary spines of *Phyllacanthus* serve 'in holding the animal rigidly in place in nooks and hollows of coral reefs and among rocks'. The only widespread living species in the genus is *P. imperialis* (Lamarck) and Clark (p. 282) described its favourite habitat as 'on the outer side of the reef below low-water mark'.

A polyporous echinoid occurring in the Batesford Limestone has been tentatively referred to *Strongylocentrotus* by Philip (1965, p. 191). Mortensen (1943) lists seven living species of *Strongylocentrotus;* they are mainly littoral forms.

There are two species each of *Heliocidaris* and *Zenocentrotus* recorded from the Recent. Mortensen (1943) states that they are littoral, living on the reef flat or among rocks. *Heliocidaris* feeds on coralline algae and other encrusting organisms (p. 342).

It is apparent that the above genera constitute a rocky, littoral fauna; they are present in the Limestone as spines, small fragments and isolated plates.

Subclass Irregularia

Large thin-tested spatangoids of the genera *Linthia, Pericosmus* and *Eupatagus* occur in the Limestone. Mortensen (1951) lists nine recent species of *Pericosmus* and five of *Eupatagus.* No living species of *Linthia* is known with certainty. The majority of the recent *Pericosmus* species are recorded from mud or sand bottom below 200 m depth, with an extreme bathymetric range of 20-550 m. *Eupatagus* has a similar depth range, having been recorded from 10-450 m.

Little information is available on the mode of life of these spatangoids. The work of Nichols (1959) on the living spatangoid genera *Spatangus, Echinocardium* and *Brissopsis,* indicates that fascioles (bands of ciliated radioles on the test) generate the water currents that a burrowing urchin uses for respiration and waste removal. Fascioles are present in *Pericosmus, Linthia* and *Eupatagus,* and it can reasonably be inferred that these echinoids were burrowers. Their exceedingly fragile tests are often found whole in the Limestone though usually more or less crushed. Even *Linthia mooraboolensis* Pritchard, which attains dimensions of 195 × 185 × 55 mm for a test thickness of only 2 mm (1908, p. 396), is preserved complete.

Comparison with Recent Echinoid Faunas

Comparison with living faunas provides further information on the habitat of the echinoids preserved in the Batesford Limestone.

Both spatangoids and regular echinoids are abundant on the Florida Keys.

Large burrowing spatangoids of the genera *Plagiobrissus* and *Meoma* occur in the bare carbonate sands of White Bank, between Key Largo and the Florida reef tract, where the water is approximately 5 m deep. The regular echinoids *Eucidaris, Echinometra, Diadema* and *Tripneustes* occur on the nearby reefs (Kier 1965).

In the carbonate sands adjacent to rock highs of the Persian Gulf (*c.* 20 m water depth) there is a rich fauna of burrowing spatangoids of the genera *Metalia, Brissopsis* and *Lovenia.* Regular echinoids *Prionocidaris, Echinometra* and *Diadema* occur on the hard bottom of the highs themselves (personal observation).

The regular echinoids *Diadema, Echinothrix, Echinometra,* and *Heterocentrotus* (see Foster 1963) and *Tripneustes* occur on the reefs of the South China Sea. Little is known of the fauna of the adjacent sand areas. However, judging from tests washed ashore—on one occasion dead and dying animals by the hundred—the spatangoid *Maretia* must be an important member of this fauna.

There are a number of differences between the Batesford Limestone echinoid assemblage and the Recent faunas outlined above. For instance, the fossil suite contains no genus from the family Diadematidae represented in the Recent faunas by *Diadema* and *Echinothrix.* Their absence is not surprising as the diadematid test is normally very fragile and, because of imbrication, is likely to break up completely when the animal dies. More difficult to explain is the almost complete absence of flat clypeasteroids at Batesford—*Clypeaster* and *Monostychia* have been recorded there but both are rare. On the other hand, *Clypeaster* and *Encope* are abundant on White Bank, and *Clypeaster* and *Echinodiscus* in the limesands of the Persian Gulf. The fact that *Clypeaster* was making its initial appearance in the Australian fossil record, and *Monostychia* was on the point of extinction, may explain their rarity at the time (Philip, personal communication).

Despite these differences, the living echinoid faunas described above are collectively similar to the assemblage found in the Batesford Limestone. However, the spatangoids and regular echinoids have been shown to occupy separate, though adjacent, niches in the Recent. Thus it is likely that only the burrowing spatangoids were indigenous to the deposit, and that the regular echinoid fragments were introduced as a constituent of the sediment.

Origin of Batesford Limestone

Chapman (1929, p. 16), on the evidence of the foraminifera, outlined the origin of the Batesford Limestone as follows:

> The ancient Batesfordian sea appears to have varied its depth within short distances, and the sediments composing the mud and shell-banks were consequently of very variable character. The Dog Rocks of the district . . . once formed a massive range of hills. Against these the shallow water shell-sand of that bygone time was washed, and piled upon the then low hummocks of granite. This evidence we may see for ourselves . . . for the lower beds of yellow limestone contain pebbles of granite similar to that of the Dog Rocks, and are in reality the shingle pebbles of the granite-skirted shores of that period.

Heron-Allen and Earland (1924, p. 123), again on foraminiferal evidence, say:

> Our material was certainly laid down in a tropical sea which was sufficiently far from a coast line to present clear water with very little precipitation of mud, as is proved by the abundance of Polyzoa and the absence of mineral grains. The depth was probably somewhere between 50-150 fathoms, judging from the known range of recent species, and the conditions must have been very similar to those existing at the present day in shallow water round the northern shores of Australia.

Stach (1936, p. 65) on the evidence of the bryozoa, deduces the environment of deposition as follows:

. . . in the Batesford quarry, the faunule is predominantly vinculariform with minor cellariform and eschariform elements, pointing to a similar bathymetric facies (i.e. about 40 metres), but quite placid water conditions.

Bowler (1963, p. 99), who chiefly examines particle size and mineralogy, explains the origin of the Batesford Limestone as follows:

The near-shore zone at the Dog Rocks became admirably suited to the development of a calcareous facies for in such a zone the following conditions were fulfilled:

1. Carbonate solubility would be low in the shallow warm water, thus facilitating its extract by shelly faunas.
2. Active currents continuously removed fines and maintained clear sandy bottom favourable to benthonic organisms.
3. Highly aerated and oxidizing conditions in the water, and on the sea floor, together with photosynthesizing algae and phytoplankton, would provide abundant food and oxygen to support a dense population on the sea floor.

None of the authors above clearly distinguish place of origin from place of deposition. Perhaps for this reason, Stach and Heron-Allan and Earland postulate moderately deep, placid conditions; Bowler shallow water and active currents, and Chapman both shallow and deeper water environment of deposition for the Batesford Limestone.

An examination of a present-day sandy bottom in clear warm shallow water—such as the skeletal carbonate sands of White Bank or the oolitic carbonate sands near Cat Cay in the Bahamas—does not reveal the dense population of benthonic organisms anticipated by Bowler. In fact, except for sediment-disturbing spatangoid and clypeasteroid echinoids, the sands have rather a desert aspect as regards megafauna.

On the other hand, the hard bottom provided by reefs or rock highs carries a comparatively profuse growth of encrusting and sedentary organisms. The fragmentary regular echinoids in the Batesford Limestone probably originated from such an area, and so could have the majority of the bryozoa, mollusc and coralline algae fragments.

As stated by Bowler (1963, p. 98) the Dog Rocks were an island in the Tertiary sea at the time of deposition of the Batesford Limestone. The combination of hard bottom and shallow water on the flanks of the Dog Rocks led to a vigorous growth of encrusting organisms which supported, in turn, a population of grazing and boring animals. Bryozoa and coralline algae would have been continually broken down by boring algae and molluscs, grazing echinoids and fish, and wave action. In the Persian Gulf dead coral is broken down by thousands of gnawing *Echinometra,* and the regular echinoids on the Dog Rocks probably filled a similar role.

Judging from the bathymetric range of living representatives of *Pericosmus* and *Eupatagus,* and the sharp relief of the Dog Rocks massif, the Batesford Limestone was deposited below the littoral zone in, say, 20-200 m water depth.

A high rate of biogenic carbonate sediment production in shallow water on the Dog Rocks, coupled with a short transportation phase down a steep submarine slope, led to the accumulation of carbonate sand (Fig. 2). The indigenous fauna of the sand certainly added to the total volume of the deposit, but its existence and character can be attributed to the presence of the Dog Rocks. The accumulation of sand only on the east and south-east side of the Rocks is an indication of the direction of prevailing wind and current at the time.

Progressive deepening of the sea resulted in the complete submergence of the Dog Rocks (Bowler 1963, p. 99) and extinction of the rich shallow-water fauna which flourished there. Local rapid production of skeletal fragments ceased, but

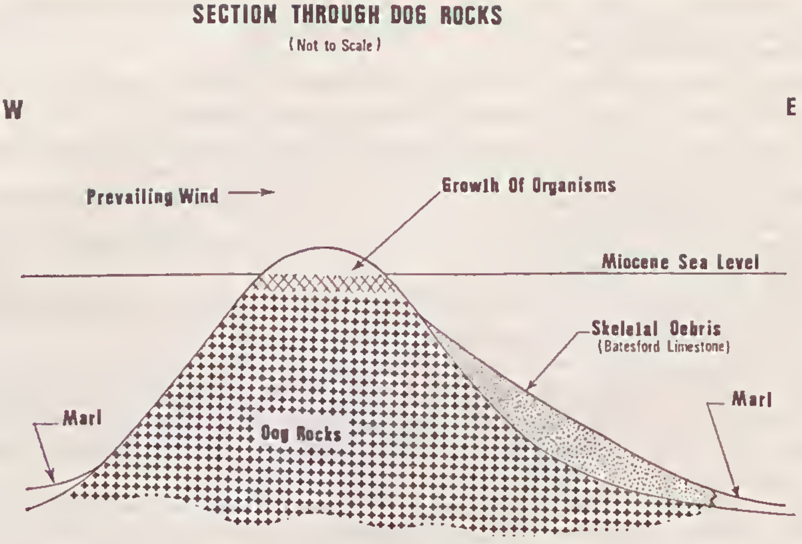

FIG. 2

widespread slow deposition of fine-grained sediment continued and carbonate sand of the Batesford Limestone passed up into marl of the Fyansford Clay.

Application to Petroleum Geology

The Batesford Limestone is surrounded and overlain by the Fyansford Clay. The Limestone itself is an excellent reservoir rock and, if buried, would have made a fine stratigraphic trap and an attractive drilling target. Initial exploration for oil off the coast of Australia will be directed towards the definition and testing of structures. However, at a later stage, exploration may include a search for stratigraphic traps and the Batesford Limestone model could then be profitably borne in mind.

The principal requirements for this type of stratigraphic trap are:

1. An area of shallow water and hard bottom—such as could be provided by a drowned erosional remnant—on which sediment-producing marine organisms could thrive.
2. Comparatively little influx of clastic sediments at the time of carbonate deposition.

If these requirements are met, there is then the possibility of an accumulation of porous and permeable skeletal lime grainstone on the lee flank of the palaeo-high.

Conclusions

The Batesford Limestone contains two distinct echinoid faunas:

(a) rock-dwelling shallow water Regularia whose fragments were a constituent of the sediment;
(b) burrowing deeper water Spatangoida which were indigenous to the Limestone itself.

The fragmentary regular echinoids, and much of the other skeletal carbonate of the Batesford Limestone, originated on the adjacent Dog Rocks. Here the hard bottom and shallow water gave rise to a vigorous growth of encrusting organisms, and thus a prolific local source of carbonate sediment was created.

In the absence of significant dilution with terrigenous clastics, skeletal particles derived from the Dog Rocks accumulated to form a carbonate sand body. Hence the Batesford Limestone owes its existence to the pre-existence of Dog Rocks. The prevailing wind and current, at time of deposition, restricted carbonate sand accumulation to only one flank of the Dog Rocks massif.

The Batesford Limestone is an excellent reservoir rock and, if buried by impermeable sediment, such a limestone would constitute a stratigraphic trap for hydrocarbons. If similar carbonate sand bodies occur in the subsurface, they are likely to be found adjacent to pre-existing topographical highs.

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